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REDUCTION OF THE BAROMETRIC PRESSURE OVER THE PLATEAU TO THE 5,000-FOOT LEVEL [1]

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INTRODUCTION

In the study of synoptic maps for the western portion of the United States, especially in connection with airways work, meteorologists repeatedly have been confronted with the imperfect state of the barometry of the plateau region. Probably the most conspicuous examples of the imperfection are to be found in certain instances in which various elements such as wind directions and state of weather indicate the presence of a cyclone over the plateau while the existence of the cyclone is not shown by the sea-level isobars. Other instances have been noted in which the sea-level pressure charts showed enclosed lows over the plateau when their existence was not substantiated either by wind circulation or by other meteorological elements. Indeed, the inaccuracies in the configurations shown by the sea-level pressure charts for the plateau region, particularly for that portion lying to the west of the Continental Divide, tend to lead those who believe in them to the conclusion that the usual concepts of the relationship of various meteorological elements to pressure configurations apply only to a very limited degree over the plateau. However, it is rather to be expected that the dynamic processes involved in producing various types of weather over the plateau are substantially the same as those involved elsewhere. This study has been undertaken in the hope of being able to support the belief that the sea-level pressure map could be advantageously supplemented by a pressure map based on pressures adjusted to a level approximately that of the surface of the plateau.

The thought of reducing pressures to a height other than sea level is not at all new. The first progressive steps along this line were probably taken by Professor Bigelow (1) who constructed tables for reducing pressures to the 3,500-foot level and to the 10,000-foot level. Later, Meisinger (2) developed an ingenious method for reducing surface pressures for the eastern two-thirds of the United States up to the 1- and 2-kilometer levels. The project which has been here undertaken differs from Bigelow's chiefly in that reductions through great depths are not attempted, while it covers a section of the United States not embraced in Meisinger's study.

In order to make possible the preparation of pressure maps for the "surface" of the plateau, only those stations lying reasonably near to the 5,000-foot level, some above and some below, have been selected. No attempt was made to reduce pressures for stations lying at or near the sea-level plane up to 5,000 feet. In this way the possible magnitude of errors due to erroneous assumptions as to the mean temperature of the reduction column is reduced to a minimum.

In attacking this problem a modified form of the hypsometric equation was used to construct tables by means of which the reduction of pressure to the 5,000-foot level could be readily performed. Considerable care was exercised in the construction of the tables and, in order that all errors apparent in the reduced pressures might be attributable to one and only one source (erroneous assumption as to mean temperature), allowance was made for all influences which could have an appreciable effect on the pressure reductions. With these precautions, one may feel secure in stating that the reduced pressures will be accurate so far as the mean temperature used in making the reduction is accurate, and that the possible errors due to the use of incorrect mean temperature arguments will be small as compared to similar errors in sea-level pressure reductions.

The advisability of applying a correction for the so-called plateau effect, particularly the correction $C \cdot \Delta\theta \cdot H$ used by Ferrel (3) and Bigelow (1) was considered. It was concluded that a plateau correction was of minor importance for the relatively short reduction columns applying from station level to the 5,000-foot level, and that if the correct temperature argument were used in obtaining the mean temperature of the air column no other temperature correction would be necessar or proper. It would appear rather that the plateau correction becomes applicable when one reduces pressures to sea level from an extensive plateau region and wishes to compare such reduced pressures with those obtained from neighboring low-lying regions. Here too, the arbitrary nature of the assumed mean temperature of the "air column" for the plateau region must come into consideration. This aspect of the situation still remains to some extent in the present attack on the problem at hand and requires a rational solution not yet perfectly attained. However, in the present instance the errors from this source are not nearly as great in general as those to be expected in the case of reductions of pressure to sea level.

In view of the above, it is expected that the synoptic pressure maps for the 5,000-foot level may be a valuable

[1] For the convenience of some who may not have had much experience in the use of the hypsometric equation, the mathematical formulae involved are given in full detail.

supplement to the maps for sea level which have been thus far used.

METHOD USED IN COMPUTING BAROMETER REDUCTION TABLES FOR THE 5,000-FOOT LEVEL

The hypsometric equation as given in the Smithsonian Meteorological Tables, 1931 edition, is:

$$(1)\qquad Z=K(1+\alpha\theta)\left(\frac{1}{1-0.378\frac{e}{b}}\right)\left(1+\frac{g_o-g_l}{g_o}\right)\left(1+\frac{h+h_o}{R}\right)\left(\log\frac{p_o}{p}\right)$$

in which

h = height of the upper station.
h_o = height of the lower station.
$Z=h-h_o$.
p = atmospheric pressure at the upper station.
p_o = atmospheric pressure at the lower station.
R = Mean radius of the earth = 20,890,127 feet.
θ = Mean temperature of the air column between the altitudes h and h_o.
e = mean pressure of aqueous vapor in the air column.
b = mean barometric pressure of the air column.
K = barometric constant = 18,400 meters or 60368 feet.
α = coefficient of the expansion of air = 0.00367 for 1° C.
g_o = standard value of gravity = 980.665 dynes.
g_l = local value of gravity.

Transposing and simplifying with justifiable approximations in the right-hand portion of the equation similar to equation on page xlii Smithsonian Meteorological Tables, 1931 edition:

$$(2)\qquad K(1+\alpha\theta)\log\frac{p_o}{p}=Z-Z\left[0.378\frac{e}{b}+\frac{g_o-g_l}{g_o}+\frac{Z+2h_o}{R}\right]$$

In English Units:

$$(3)\qquad 60368[1+0.002039(\theta-32)]\log\frac{p_o}{p}=Z-Z\left[0.378\frac{e}{b}+\frac{g_o-g_l}{g_o}+\frac{Z+2h_o}{R}\right]$$

In the above equation (3) let K' represent the term $60368[1+0.002039(\theta-32)]$. Then obviously K' is identical to $K=60368$ when $\theta=32°$ F. Values of K' for other temperatures, and their logarithms used in the construction of the reduction tables are as follows:

θ °F.	Values of K'	$\log_{10} K'$	θ °F.	Values of K'	$\log_{10} K'$
−20	53967.3	4.73213	50	62583.6	4.79646
−10	55198.2	4.74192	60	63814.5	4.80492
0	56429.1	4.75150	70	65045.4	4.81322
10	57660.0	4.76087	80	66276.3	4.82136
20	58890.9	4.77005	90	67507.2	4.82935
30	60121.8	4.77903	100	68738.1	4.83720
40	61352.7	4.78783			

By combining the temperature term $[1+0.002039(\theta-32)]$ with K instead of applying a portion of it as a correction to Z, the computation of reduction tables is somewhat simplified as well as more exact.

The gravity term $\left(\frac{g_o-g_l}{g_o}\right)$ was handled as follows: For stations below the 5,000-foot level, where corrections for gravity anomaly, topography and compensation are known, i.e., Mount Hamilton, Winnemucca, Salt Lake, Lander, Grand Junction, Sheridan, and El Paso, the value of g_l (local gravity) was computed.

EXAMPLE A

Mount Hamilton, elevation 4,212.6 feet, latitude 37°20.4′, longitude 121°38.6′:

	Dynes
Mean gravity at sea-level, corresponding to latitude 37°20.4′, table 90, Smithsonian Meteorological Tables, fifth edition	979.937
Correction for height −0.000094×4212.6	−.396
Correction for gravity anomaly (U.S.C.G.S. special publication no. 40, by Wm. Bowie)	−.003
Correction for topography and compensation special publication no. 40, by Wm. Bowie	+.120
Local gravity	979.658

$$\left(\frac{g_o-g_l}{g_o}\right)=\frac{980.665-979.658}{980.665}=0.00102$$

$$Z\left(\frac{g_o-g_l}{g_o}\right)=787.4\times0.00102\ =\ .803\text{ ft.}$$

In all cases where the value of local gravity was thus known, the value of h_o in the gravity correction term for altitude $Z\left(\frac{Z+2h_o}{R}\right)$ was employed as *zero*, because the correction for height of the lower station is taken care of in the computation of local gravity and correction to standard gravity (see above computations). Substituting values for Mount Hamilton:

EXAMPLE B

$$Z\left(\frac{Z+2h_o}{R}\right),\ 787.4\left(\frac{787.4+0}{20,890,127}\right)=0.03\text{ ft.}$$

For stations above the 5,000-foot level where corrections for gravity anomaly, topography, and compensation are known, i.e., Rock Springs, Denver, and Tonopah, the value of local gravity at the station elevation was computed as in example A. The reduction of the local station gravity to gravity at the 5,000-foot level was accomplished as follows:

EXAMPLE C

Rock Springs, Wyo., elevation 6,374.42 feet.
Value of local station gravity, 979.727 dynes.

g_l at 5,000-foot level $=979.727\left(1+\frac{2Z}{R}\right)$. That is, $979.727\left(1+\frac{2748.84}{20,890,127}\right)=979.857$ dynes, the value of g_l at the 5,000-foot level. This last gravity value makes the expression $Z\left(\frac{g_o-g_l}{g_o}\right)=1.132$ feet. In this case also the value of h_o was employed as *zero* in the expression $Z\left(\frac{Z+2h_o}{R}\right)$.

For all other stations, the value of local gravity was unknown and the correction was computed as follows:

EXAMPLE D

Helena, Mont., elevation 4,123.7 feet, latitude 46°34′.

$Z\left(\frac{g_o-g_l}{g_o}\right)$ was taken as equal to $Z(0.00264\cos 2\phi-0.000007\cos^2 2\phi+0.000045)$

Substituting latitude for ϕ and solving gives $Z(-0.00008958294463)=-0.043$ foot.

g_l here represents local gravity at sea level.

In all such cases where the value of local gravity was unknown and the computed correction was for gravity at *sea level* at the latitude of the station, the altitude

(h_o) in the second gravity correction term $\left[Z\left(\frac{Z+2h_o}{R}\right)\right]$ was taken as the height of the lower level above sea level, whether it was the adopted "station elevation" or 5,000 feet, the level to which reductions of barometric pressure were made.

The correction for water vapor $\left[Z\left(0.378\frac{e}{b}\right)\right]$ contains a ratio of the mean pressure of water vapor in the air column to the mean barometric pressure of the air column and cannot be obtained directly by surface observations. Combining Hann's (4) equation for the decrease of vapor pressure with height in mountainous regions $[e=e_o\ (10^{-\frac{Z}{20670}})]$ with $[B=B_o\ (10^{-\frac{Z}{60368}})]$, the approximate hypsometric relationship, the following equation is arrived at—

$$(4)\qquad \left(\frac{e}{B}\right)=\left(\frac{e}{B}\right)_o 10^{-0.0000317Z}, \text{ approximately.}$$

$\left(\frac{e}{B}\right)$ represents the ratio of vapor pressure to pressure at the upper level and $\left(\frac{e}{B}\right)_o$ represents the ratio of vapor pressure to pressure at the lower level. By integral calculus the mean value $\left[Z\left(0.378\ \frac{e}{b}\right)\right]$ required in the formula is found to be:

$$(5)\qquad 5170\left(\frac{e}{B}\right)_o[1-10^{-0.0000317Z}]$$

Substituting the value of Z for all stations below the 5,000-foot level and solving gives a constant times $\left(\frac{e}{B}\right)_o$ which is used in place of $\left[Z\left(0.378\ \frac{e}{b}\right)\right]$ in the original equation and $\left(\frac{e}{B}\right)_o$ represents station observations. Substituting the value of Z for Mount Hamilton in expression (5) as an example:

$$5170\left(\frac{e}{B}\right)_o[1-10^{-(0.0000317)(787.4)}]=288.796\left(\frac{e}{B}\right)_o$$

For stations above the 5,000-foot level, the correction must be obtained in terms of station observations $\left(\frac{e}{B}\right)$, instead of $\left(\frac{e}{B}\right)_o$.

$$(6)\qquad \left(\frac{e}{B}\right)_o=\frac{e}{B}(10^{0.0000317Z})$$

and substituting in (5)

(7) mean value of $Z\left(0.378\frac{e}{b}\right)=5170\left[\left(\frac{e}{B}10^{0.0000317Z}\right)\right][1-10^{-0.0000317Z}]$

Substituting the value of Z for each station and solving gives a constant times $\left(\frac{e}{B}\right)$ which is used in place of $Z\left(0.378\ \frac{e}{B}\right)$ in the original equation and $\left(\frac{e}{B}\right)$ represents station observations.

In this manner all of the values to be substituted in the hypsometric formula (3) were obtained. Substitutions in the case of Mount Hamilton, elevation 4,212.6 feet, $Z=787.4$ feet, follow as an example:

$$K'\log_{10}\frac{B_o}{B}=787.4-288.796\left(\frac{e}{B_o}\right)-0.803-0.03$$

It is obvious that no single table giving values of B (pressure at 5,000 feet in the above example) can be constructed for changing values of K', B_o, and e. Therefore, reduction tables for dry air were constructed omitting the correction for vapor pressure $\left(-288.796\ \frac{e}{B_o}\right)$ in the above case. Separate tables were constructed giving corrections for vapor pressure to be applied to the reduced pressures for dry air. These corrections are independent of variations in station pressure and were constructed from the following formulae:

For stations below the 5,000-foot level—

Let B_o = station pressure.
e = vapor pressure at the station elevation.
K' = barometric constant corrected for temperature.
B = pressure at 5,000 feet uncorrected for vapor pressure.
B' = pressure at 5,000 feet corrected for vapor pressure.
Z' = Z corrected for both gravity terms.
X = the constant in vapor pressure correction term.

Then

$$K'\log_{10}\frac{B_o}{B'}=Z'-X\frac{e}{B_o}\ \text{ and }\ K'\log_{10}\frac{B_o}{B}=Z'$$

Subtracting

$$(\log B_o-\log B')-(\log B_o-\log B)=\frac{Z-X\frac{e}{B_o}}{K'}-\frac{Z'}{K'}$$

$$\log B'-\log B=\frac{Xe}{B_oK'}\ \text{ and }\ B'=B\left(10^{\frac{Xe}{B_oK'}}\right)$$

The correction desired for vapor pressure is $B'-B$,

$$(8)\qquad B'-B=B\left(10^{\frac{Xe}{B_oK'}}\right)-B$$

Vapor pressure corrections $(B'-B)$ which are to be applied to the reduced pressure for dry air are determined by three variables, viz, vapor pressure, mean temperature, and station pressure. For all stations used in this study a range of 2.5 inches in station pressure will not change the correction in the third decimal place and thus average station pressure can be used as a constant for the computation. Mean temperature changes below 60° affect only the fourth decimal place of the correction but changes above 60° in mean temperature may change the correction by 0.001 inch, particularly at vapor pressures above 0.500 inch. By selecting 60° as a constant mean temperature, the corrections were computed for average station pressure for all values of vapor pressure. The corrections will not be in error more than 0.001 inch in extreme cases and exact to one thousandth of an inch for the majority of cases. This approximation is justifiable in order that the work of reducing barometers at the various stations may be simplified. After the corrections were computed the vapor pressures were converted to dew point for greater ease in handling the observational data.

For stations above the 5,000-foot level, the formula for vapor pressure correction reduces to:

$$B_o' - B_o = B_o\left(10^{-\frac{Xe}{BK'}}\right) - B_o \qquad (9)$$

Where

B_o' is the pressure at the 5,000-foot level corrected for vapor pressure.

B_o is the pressure at the 5,000-foot level uncorrected for vapor pressure.

B is the station pressure.

The corrections computed from the above formula are of negative sign and are to be applied to the reduced pressure.

The barometer reduction tables for dry air were computed to give values of $B_o - B$ at intervals of each 10° F. temperature from −20 to 100 and intervals of one-tenth inch of station pressure over a range of 2.400 inches. These tables allow easy interpolation. The value of $B_o - B$ and the dew point correction are both added to station pressure to obtain the pressure at the 5,000-foot level.

The values of $B_o - B$ for dry air at a given temperature are linear with respect to station pressure. Because of this fact a method for rapid computation of the tables was used. It was only necessary to compute an exact value to 4 decimals for each 10° of temperature and the lowest station pressure desired, then compute a similar value for a hypothetical pressure 10 inches higher, subtract the former from the latter, point off the proper decimals for intervals of one-tenth inch and add this value repeatedly to the first value, using an adding machine. Subtotals were taken between each addition and these were the values of $B_o - B$ in intervals of one-tenth inch station pressure for a given temperature.

Example (Mount Hamilton):

$$K' \log_{10}\frac{B_o}{B} = 787.4 - 288.796\left(\frac{e}{B}\right)_o - 0.803 - 0.03$$

For dry air the correction for vapor pressure is neglected and the remainder is combined:

$$K' \log_{10}\frac{B_o}{B} = 786.6, \text{ transposing } B = \frac{B_o}{\text{antilog}\left(\frac{786.6}{K'}\right)}$$

Dividing 786.6 by 60121.8 the value of K' at 30°

$$B = \frac{B_o}{\text{antilog } (0.013083)}$$

It is desired to construct the table at intervals of one-tenth inch from the lowest station pressure of 24.400 inches, then,

$$B = \frac{24.400}{\text{antilog } (0.013083)}, \quad \log 24.400 = 1.387390$$

$$\begin{array}{r} 1.387390 \\ -.013083 \\ \hline \text{antilog } 1.374307 = 23.6759 \\ \text{pressure at 5,000 feet} \end{array}$$

Similarly for a hypothetical pressure of 34.40 inches,

$$B = \frac{34.400}{\text{antilog } (0.013083)}, \quad \log 34.400 = 1.536558$$

$$\begin{array}{r} 1.536558 \\ -.013083 \\ \hline \text{antilog } 1.523475 = 33.3792 \\ \text{pressure at 5,000 feet} \end{array}$$

For 34.40 inches $B_o - B = 34.400 - 33.3792 = 1.0208$

For 24.40 inches $B_o - B = 24.400 - 23.6759 = .7241$

subtracting .2967

Dividing by 100 to obtain the change for each one-tenth inch gives 0.002967 and adding this value repeatedly to 0.7241 gives the values of $B_o - B$ for 30° in intervals of one-tenth inch station pressure from 24.400.

B_o	$B_o - B$	
24.400	0.724100	only three decimal places used.
	.002967	
24.500	.727067s	
	.002967	
24.600	.730034s	
	.002967	
24.700	.733001s	
	etc.	

It is necessary now to devise some means for securing the mean temperature of the air column between station elevations and the 5,000-foot plane. Stations over the plateau whose elevations are not far distant from the 5,000-foot level were selected purposely in order to minimize the error when an arbitrary mean temperature of the air column is assumed.

The arbitrary mean temperature expressed by the value

$$\frac{\text{current temperature} + \text{temperature 12 hrs previous}}{2}$$

was graphed using averages of many hourly temperatures over a period of time. It was found that the curve is at a maximum between 1 and 2 a.m. and p.m., and a minimum between 7 and 8 a.m. and p.m. local time. It is entirely out of phase with the diurnal variation of surface temperature and undoubtedly out of phase with the mean temperature of a relatively short air column. A graph of Mount Weather temperatures at 1,500 feet above the surface indicates that the diurnal variation of mean temperature for this layer at least is in phase with the surface temperature but of less amplitude. The temperature records at Drexel, Nebr., (5) "show that the diurnal phase in the free air is not greatly different from that at the surface, but that the amplitude diminishes to about 1° C. at 1,500 meters, remaining practically unchanged from that level up to an altitude of 3,500 meters. * * * Naturally the diurnal variation is greater in clear than in cloudy weather * * *".

It would be better, therefore, to use an arbitrary mean computed from current and previous temperatures which would have a diurnal variation in phase with the surface temperature but of less amplitude. A curve with such characteristics can be obtained by the formula:

(2×current temperature + Temperature 4 hours previous + Temperature 12 hours previous) ¼

Although the advantages of such a mean temperature argument are recognized, yet for simplicity the mean temperature used in sea-level reductions should be used in reductions to the 5,000-foot level. Therefore, the mean of the current temperature and temperature 12 hours previous was used in constructing a series of synoptic maps for the 5,000-foot level.

In attempting to reduce station pressures downward to the 5,000-foot level as well as upward to this level, an arbitrary mean temperature must be corrected, increasing it for downward reductions and decreasing it for upward reductions. In the absence of aerological data over the plateau, the average lapse rates were computed from Bigelow's Tables No. 34, volume II, Report of the Chief of the Weather Bureau 1900–1901. From these tables the vertical temperature rise or fall was interpolated between each station elevation and the 5,000-foot level for each month of the year and reduced to a mean correction for applying to the arbitrary mean temperature (see table 2).

THE REDUCTION OF THE BAROMETRIC PRESSURE TO THE 5,000-FOOT LEVEL FOR CALGARY, CANADA

The elevation of Calgary, 3,389 feet, is high enough to make reductions of pressure to the 5,000-foot level with reasonable accuracy. All other Canadian stations reporting regularly have a lower elevation and cannot be used successfully with this method.

Tables were prepared for reducing the sea-level pressure, which is given in the signal reports, backwards to the true station pressure and then reducing this station pressure to the 5,000-foot level. Assuming that Calgary at present uses Bigelow's original table for reduction to sea-level, a table was constructed for the reduction backwards from that given on page 968 vol. 2 of the Chief's Report 1900–1901. This table, taken from Bigelow, gave true "station pressure" for the elevation 3,389 feet. A second table was constructed for the reduction from 3,389 feet to the 5,000-foot level using the same method as has already been described with the exception that average humidity values, page xlviii Smithsonian Meteorological Tables, were incorporated in the computations. In preparing these 2 tables it was discovered that they could be accurately combined into 1 table and this was done. The 5,000-foot pressures obtained from the latter table, using as arguments the mean 12-hourly temperatures and the sea-level pressures from the "signal" reports, are thus reasonably accurate. It is intended that a copy of the Calgary reduction table be supplied to stations where the 5,000-foot pressure maps are to be prepared so that the reduction can be accomplished after receipt of the Calgary report.

THE REDUCTION OF BAROMETRIC PRESSURE TO THE 5,000-FOOT LEVEL FOR INTERMEDIATE AIRWAYS STATIONS EQUIPPED WITH ANEROID BAROMETERS

With few exceptions, intermediate airways stations over the Plateau report station pressure in the hourly weather sequences. Such pressures are not readily comparable, and are valueless to meteorologists and pilots except to show short period pressure changes. If the pressures obtained from aneroid barometers could be successfully reduced to the 5,000-foot level over the Plateau and thus entered in the sequence observations, they could be used to supplement the readings from mercurial barometers. All pressures at intermediate stations would be comparable and their value for indicating short period pressure changes would not be impaired. They would be particularly valuable in locating ill-defined wind-shift lines.

It is rare that the elevation of an intermediate airway station is known with sufficient accuracy for work in barometry. It may be possible to have levels run to all airways stations at some future time. For the present, however, the plan is to "adopt" an elevation for each station after every effort has been made to obtain the true elevation. This was done for a number of stations in Nevada, Utah, Idaho, and Montana, and the reduction computed to the 5,000-foot level to two decimal places. Average humidity was incorporated in the tables.

It is known that some aneroid barometers drift from their true setting over a period of time and that this error cannot be accurately determined except by comparison with a mercurial barometer at the station. Mercurial barometers are not ordinarily available to make such comparisons. However, periodical comparisons of reduced pressures from intermediate stations can be made with surrounding 5,000-foot pressures reported by stations with mercurial barometers at times when the maps are "flat" and upper-air winds are gentle. A correction can be determined for each station equipped with an aneroid barometer and instructions issued to such stations to apply the correction to all readings. A correction obtained in this manner will in reality be approximately the sum of two unknown corrections, i.e., a removal correction to the adopted elevation, and an instrumental error correction. If mercurial barometers are installed at some of the intermediate stations and elevations accurately determined, new tables based upon the true station elevation would be computed.

SYNOPTIC MAPS FOR THE 5,000-FOOT LEVEL

Isobaric charts for the 5,000-foot level were prepared for the month of April 1932 using data for 38 high-altitude stations, 30 of which were equipped with mercurial barometers. One of the charts is shown in figure 1 in comparison with the sea-level chart. The upper-air winds for the 6,000-foot level were placed on each map and were in good agreement with the isobars. Pressure gradients were not so pronounced on the 5,000-foot maps as the sea-level maps. Poorly defined centers of low pressure were more easily traced from day to day over the Plateau on the 5,000-foot maps than on the sea-level maps. The "heat low" in the California valleys at sea level was not found on the 5,000-foot maps. Secondary depressions over southern Utah on the sea-level charts were not found on the 5,000-foot maps.

The sea-level maps should, of course, be continued, but supplemented by 5,000-foot pressure maps for the Plateau. The latter maps will be quite useful in locating poorly defined fronts which move in from the Pacific Ocean. The pressure data for this level would be useful in drawing streamlines on the proper upper air wind chart and such lines could be extended over the plains region with some degree of confidence.

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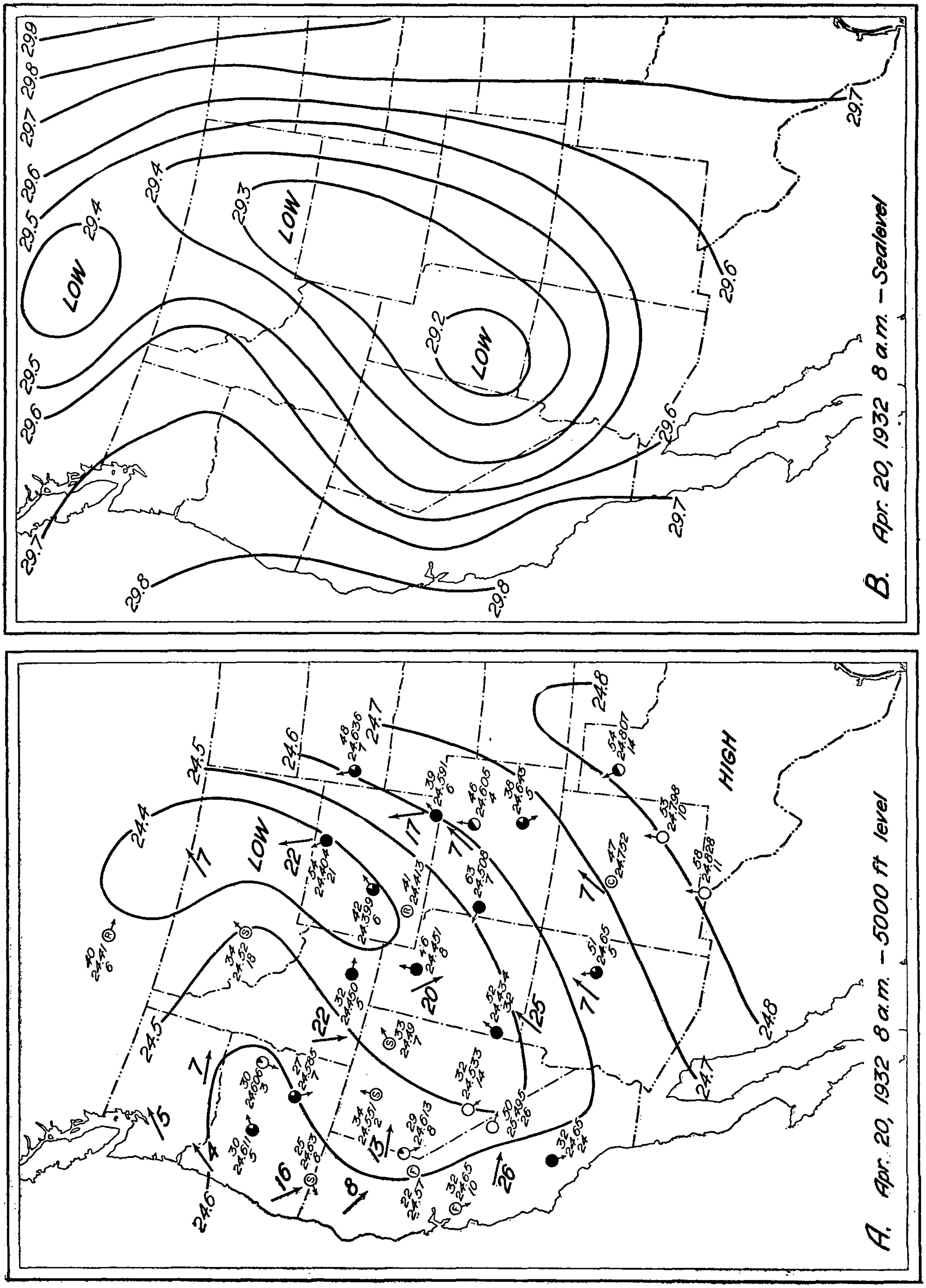

FIGURE 1.—Isobaric chart for the 5,000-foot level as compared with the sea-level chart for 8 a.m., April 20, 1932. Upper-air winds for the 6,000-foot level are shown on chart A.

TABLE 1.—*Constants used in hypsometric equation for the various stations*

Stations	Elevation	Z	$Z\left(0.378\frac{e}{b}\right)$	$Z\left(\frac{g_o-g_l}{g_o}\right)$	g_l	$Z\left(\frac{Z+2h_o}{R}\right)$
Albuquerque, N.Mex.	4,971.7	28.3	$10.702\left(\frac{e}{b}\right)$[2]	0.027	(1)	0.01
Amarillo, Tex	3,614.3	1,385.7	$497.354\left(\frac{e}{b}\right)$[2]	1.286	(1)	.57
Baker, Oreg	3,470.6	1,529.4	$546.055\left(\frac{e}{b}\right)$[2]	.102	(1)	.62
Bend, Oreg	3,632.2	1,367.8	$491.305\left(\frac{e}{b}\right)$[2]	.181	(1)	.56
Blue Canyon, Calif	5,275.5	275.5	$106.045\left(\frac{e}{b}\right)$[2]	.157	(1)	.13
Burns, Oreg	4,211.7	788.3	$289.106\left(\frac{e}{b}\right)$[2]	.137	(1)	.35
Calgary, Alberta	3,389.0	1,611.0	----------	–.945	(1)	.645
Cheyenne, Wyo	6,143.8	1,143.8	$447.948\left(\frac{e}{b}\right)$[2]	.458	(1)	.61
Denver, Colo	5,331.7	331.7	$126.696\left(\frac{e}{b}\right)$[2]	.345	979.612	.004
Elko, Nev	5,076.5	76.5	$29.01\left(\frac{e}{b}\right)$[2]	.033	(1)	.04
El Paso, Tex	3,915.7	1,084.3	$393.385\left(\frac{e}{b}\right)$[2]	1.721	979.109	.056
Grand Junction, Colo.	4,602.2	397.8	$147.862\left(\frac{e}{b}\right)$[2]	.422	979.629	.01
Helena, Mont	4,123.7	876.3	$320.333\left(\frac{e}{b}\right)$[2]	–.043	(1)	.383
Independence, Calif	3,957.3	1,042.7	$378.931\left(\frac{e}{b}\right)$[2]	.823	(1)	.447
Lander, Wyo	5,372.0	372.0	$142.366\left(\frac{e}{b}\right)$[2]	.273	979.911	.01
Modena, Utah	5,473.1	473.1	$181.682\left(\frac{e}{b}\right)$[2]	.333	(1)	.238
Mount Hamilton, Calif.	4,212.6	787.4	$288.796\left(\frac{e}{b}\right)$[2]	.803	979.658	.03
Pocatello, Idaho	4,477.6	522.4	$229.651\left(\frac{e}{b}\right)$[2]	.126	(1)	.258
Pueblo, Colo	4,806.0	194.0	$72.897\left(\frac{e}{b}\right)$[2]	.131	(1)	.091
Rapid City, S.Dak	3,259.0	1,741.0	$616.988\left(\frac{e}{b}\right)$[2]	.228	(1)	.688
Reno, Nev	4,400.4	599.6	$221.379\left(\frac{e}{b}\right)$[2]	.256	(1)	.27
Rock Springs, Wyo	6,374.42	1,374.42	$545.367\left(\frac{e}{b}\right)$[2]	1.132	979.727	.09
Roswell, N.Mex	3,565.5	1,434.5	$513.898\left(\frac{e}{b}\right)$[2]	1.541	(1)	.588
Salt Lake City, Utah	4,226.6	773.4	$283.833\left(\frac{e}{b}\right)$[2]	.673	979.812	.029
Sandberg, Calif	4,523.3	476.7	$176.814\left(\frac{e}{b}\right)$[2]	.462	(1)	.22
Sheridan, Wyo	3,790.2	1,209.8	$436.865\left(\frac{e}{b}\right)$[2]	.514	980.248	.07
Siskiyou Summit, Oreg.	4,530.0	470.0	$174.332\left(\frac{e}{b}\right)$[2]	.147	(1)	.23
Tonopah, Nev	6,089.5	1,089.5	$427.917\left(\frac{e}{b}\right)$[2]	1.253	979.443	.06
Winnemucca, Nev	4,343.9	656.1	$241.749\left(\frac{e}{b}\right)$[2]	.553	979.838	.02
Winslow, Ariz	4,882.5	117.5	$44.152\left(\frac{e}{b}\right)$[2]	.111	(1)	.06

[1] Value for local gravity not known: $Z\left(\frac{g_o-g_l}{g_o}\right)$ taken as equal to $Z(.00264\cos 2\phi - 0.000007\cos^2 2\phi + 0.000045)$.

[2] $\left(\frac{e}{b}\right)$ refers to ratio of vapor pressure to total pressure at the station.

TABLE 2.—*Corrections to be applied to surface mean-temperature arguments to allow for average vertical temperature gradients*

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Albuquerque	0	0	0	0	0	0	0	0	0	0	0	0	0
Amarillo	–1.4	–1.5	–1.6	–1.9	–2.0	–2.4	–2.2	–2.3	–2.0	–1.8	–1.6	–1.5	–1.9
Baker	–2.6	–3.1	–2.8	–3.0	–4.8	–4.4	–2.8	–3.2	–2.5	–2.2	–2.9	–3.9	–3.2
Bend	–2.4	–2.9	–2.8	–2.8	–4.5	–4.2	–2.6	–3.0	–2.4	–2.0	–2.9	–3.3	–3.0
Blue Canyon	+.5	+.4	+.3	+.4	+.3	+.4	+.3	+.3	+.3	+.3	+.5	+.3	+.4
Burns	–1.4	–1.3	–1.5	–1.5	–2.1	–2.0	–1.3	–1.5	–1.2	–1.1	–1.6	–1.7	–1.5
Cheyenne	+1.6	+1.1	+1.7	+1.9	+1.7	+1.6	+1.6	+1.6	+1.5	+1.6	+2.0	+2.0	+1.7
Denver	+.2	0	+.3	+.5	+.5	+.4	+.4	+.5	+.4	+.4	+.3	+.4	+.4
Elko	+.1	+.1	+.2	+.2	+.2	+.2	+.1	+.1	+.1	+.1	+.2	+.2	+.2
El Paso	–1.5	–1.2	–1.3	–1.5	–1.7	–1.5	–1.9	–2.0	–1.9	–1.4	–1.4	–1.5	–1.6
Grand Junction	–.2	0	–.3	–.5	–.6	–.5	–.6	–.6	–.7	–.5	–.5	–.5	–.5
Helena	–1.6	–1.5	–1.6	–1.6	–1.7	–1.7	–1.4	–1.2	–1.2	–1.2	–1.5	–1.9	–1.5
Independence	–1.4	–1.1	–1.3	–1.3	–1.4	–1.4	–1.2	–1.4	–1.2	–1.2	–1.5	–1.5	–1.3
Lander	+.8	+.5	+1.0	+.7	+.9	+.9	+.8	+.6	+.7	+.7	+1.0	+1.2	+.8
Modena	+.6	+.4	+.6	+.8	+.8	+.9	+.9	+.8	+.7	+.7	+.9	+.7	+.7
Mt. Hamilton	–1.1	–.9	–1.1	–1.0	–1.0	–1.0	–.8	–1.0	–.9	–.9	–1.2	–1.2	–1.0
Pocatello	–.8	–.5	–.8	–.8	–1.0	–1.0	–.8	–.7	–.8	–.7	–.9	–1.1	–.8
Pueblo	–.2	–.1	–.2	–.3	–.2	–.2	–.2	–.2	–.2	–.2	–.2	–.2	–.2
Rapid City	–1.2	–1.2	–1.4	–2.5	–2.6	–2.5	–2.4	–1.8	–2.1	–2.2	–.9	–1.7	–1.9
Reno	–1.0	–.7	–1.0	–1.0	–.9	–.8	–.7	–.7	–.8	–.9	–1.0	–.8	–.9
Rock Springs	+2.2	+1.6	+2.2	+2.5	+2.6	+2.2	+2.3	+2.4	+2.0	+2.4	+3.3	+3.0	+2.4
Roswell	–1.8	–1.5	–1.7	–2.0	–2.1	–2.3	–2.1	–2.5	–2.3	–1.8	–1.8	–1.8	–2.0
Salt Lake	–.6	0	–.5	–1.0	–1.0	–1.4	–1.1	–1.0	–1.0	–.9	–1.0	–1.0	–.9
Sandberg	–.6	–.5	–.6	–.6	–.6	–.7	–.4	–.7	–.6	–.4	–.7	–.8	–.6
Sheridan	–1.7	–1.3	–1.5	–1.9	–2.2	–2.1	–1.7	–1.3	–1.4	–1.6	–1.3	–2.2	–1.7
Siskiyou Smt	–.8	–.8	–.9	–.8	–1.1	–1.1	–.8	–.8	–.8	–.8	–.7	–.9	–.9
Tonopah	+1.8	+1.5	+1.6	+1.8	+1.6	+1.9	+1.5	+1.6	+1.6	+1.6	+2.1	+1.8	+1.7
Winnemucca	–1.1	–.8	–1.0	–1.0	–1.2	–1.1	–.9	–.9	–.9	–.9	–1.1	–1.0	–1.0
Winslow	–.2	–.2	–.1	–.2	–.2	–.3	–.3	–.3	–.2	–.2	–.2	–.2	–.2

LITERATURE CITED

(1) Report of the Chief of the Weather Bureau, 1900–1901, volume II.

(2) Monthly Weather Review Supplement No. 21.

(3) Report of the Chief Signal Officer, 1886, appendix 23.

(4) J. Hann and R. Süring, Lehrbuch der Meteorologie, fourth edition, 1926, page 244.

(5) Monthly Weather Review Supplement No. 20.